Advances in Concrete Construction, *Vol. 3, No.* 3 *(2015) 223-236*
DOI: http://dx.doi.org/10.12989/acc.2015.3.3.223

Strength evaluation of concrete with fly ash and GGBFS as cement replacing materials

H.S.Chore* and M.P. Joshi[a]

Department of Civil Engineering, Datta Meghe College of Engineering, Sector-3, Airoli, New mumbai-4007078, Maharashtra, India

(Received September 30, 2015, Revised December 19, 2015, Accepted December 23, 2015)

Abstract. Concrete is the most widely used material of construction. Concrete gained the popularity as a construction material due to the easy availability of its component materials, the easy formability, strength and rigidity upon setting and curing.In construction industry, strength is the primary criterion in selecting a concrete for a particular application. Now a days, the substantial amount of waste materials, containing the properties of the Pozzolana, is being generated from the major industries; and disposal of such industrial wastes generated in abundance is also a serious problem from the environmental and pollution point of view. On this backdrop, efforts are made by the researchers for exploring the possible utilization of such waste materials in making the sustainable construction material. The present paper reports the experimental investigations to study the strength characterization of concrete made from the pozzolanic waste materials. For this purpose, the Pozzolanic materials such as fly ash and ground granulated blast furnace slag were used as a cement replacing materials in conjunction with ordinary Portland cement. Equal amount of these materials were used in eight trial mixes with varying amount of cement. The water cement ratio was also varied. The chemical admixture was also added to improve the workability of concrete. The compressive strengths for 7, 28, 40 and 90 days' were evaluated whereas the flexural and tensile strengths corresponding to 7, 28 and 40 days were evaluated. The study corroborates that the pozzolanic materials used in the present investigation along with the cement can render the sustainable concrete.

Keywords: concrete; strength; pozzolanic materials; fly ash; ground granulated blast furnace slag (GGBFS)

1. Introduction

The concrete is a versatile construction material owing to the benefits it provides in terms of strength, durability, availability, adoptability and economy. It is a heterogeneous mix of cement, water and theaggregates. Great efforts have been made to improve the quality of concrete by various means in order to raise and maximize its level of performance. Using same ingredients with little adjustments in the micro- structure (and probably adding specific materials), it is possible to obtain some of the special types of concrete such as high performance concrete (HPC),

*Corresponding author, Professor, E-mail: hschore@rediffmail.com
[a]Assistant Professor, E-mail: mpjoshi19@gmail.com

http://www.techno-press.org/?journal=acc&subpage=7 ISSN: 2234-0912 (Print), 2234-179X (Online)

self compacting concrete (SCC) and roller compacted concrete, high volume fly ash concrete (HVFAC), etc.

The development of these concretes has brought forth the need for admixtures, both- mineral and chemical, to improve the performance of concrete. By-products from various industries cause a major environmental problem around the world. In order to encourage waste recycling and prevent waste dumping, a landfill tax has also been imposed in the developed countries. However, the waste dumping is still a serious environmental issue throughout the world. Amongst various by-products generated by the industries, Fly Ash (FA) and Ground Granulated Blast-Furnace Slag (GGBFS) have attracted much attention by concrete researchers. The admixtures may be added in concrete in order to enhance some of its properties desired specially. Very fine materials such as fly ash, a product of coal-burning power plant, render the fresh concrete more plastic. Ground Granulated Blast Furnace Slag (GGBFS) is a by-product from the blast furnaces used to make iron.

2. Brief review of the literature

There have been several studies reporting the utilization of pozzolanic waste materials such as fly ash and ground granulated blast furnace slag. Kohubu (1969) long back pointed out the utilization of fly ash in making the concrete. Thereafter, many researchers worked on the theme. Some of the significant works are reviewed briefly in this section. Oluokun (1994) worked for fly ash- cement and fly ash concrete mix design. Malhotra (1999) described the amount of CO2 being contributed by the Portland cement industry and discussed how these emissions can be reduced considerably by the increased use of large volumes of fly ash and other supplementary cementing materials in the concrete industry. Obla and Russell (2003) discussed the fresh and hardened properties of concrete made with an ultra-fine fly ash (UFFA) produced by air classification.

Dhadse *et al.* (2008) presented a review of different ways of using fly ash and subsequently, the policies of Govt. of India regarding utilization and disposal of fly ash. Environmental and occupational health hazards associated with fly ash were also discussed. Aggarwal and Gupta (2010) reported the development of high volume fly ash concrete for construction with reference to its predecessors like HSC and HPC. Different ways of using Fly ash in various sectors of civil engineering construction industry in India were presented by Alam and Akhtar (2011). Yang and Li (2012) and Sunil and Manjunatha (2015) discussed the effects of fly ash as a partial replacement of cement on the strength of concrete. Silva and Brito (2013) reported the study on the effect of fly ash along with the limestone filler on the electrical resitivity and capillarity properties of the self compacting concrete (SCC). It was found that there was a significant improvement in these properties with the addition of these materials. Sunil *et al.* (2015) reported the potential use of mine tailings and fly ash in concrete. The mine tailings and fly ash were used as a replacement of fine aggregates and cement, respectively. However, no significant improvement in the strengths was observed. Further, Aggarwal and Gupta (2012) again concluded the use of High Volume Fly ash Concrete (HVFC) in construction.

The studies concerning the utilization of ground granulated blast furnace slag (GGBFS) in conjunction with cement are reported by few researchers. Meusel and Rose (1983) worked for production of granulated blast furnace slag at sparrows point and studied the workability and strength potential of concrete incorporating the slag. Daube and Bakker (1986) concluded that slag cement about 85% slag, has been proven to be low heat with a sufficient level of strength to allow the building of dams.

Dubovoy *et al.* (1986) performed tests for three manufacturers of groundgranulated blast furnace slag to determine the performance of their products with Portland cement and concluded that use of slag can be beneficial without resulting in significant technical problems or adverse construction problems. Frigione (1986) showed that 'the resistance to sulfates and to alkali aggregate reaction remains very strong if the slag percentage in the cement is high'. Wimpenny *et al.* (1989) presented the findings from low temperature curing conditions. Mixes with three cementitious contents and three OPC/GGBFS blends at constant water content were prepared. Upon casting the specimen were immediately transferred to four different regimes (40°, 20°, 10°and 5°). Folarin *et al.* (1998) studied the influence of particle-size distribution (PSD) of ground granulated blast-furnace slag (GGBFS) on the compressive strength of slag mortar.

Osborne (1999) reported the performance and long-term durability of concrete where ground glassy blast -furnace slag (granulated and pelletized) was used as a cementitious material. Ganesh Babu and Rama Kumar (2000) suggested the methodology of designing the concretes made from GGBFS for a desired strength at any given percentage of replacement. Hooton (2000) reported the use of GGBFS as a supplementary cementing material for enhanced performance of concrete.

Corrosion of reinforcement embedded in concrete causes most of the failures in concrete structures. Pal *et al.* (2002) worked along the similar lines and reported in detail the study on the behaviour of concrete made from GGBFS, obtained from some premier steel manufacturing plants in India, on the rate and amount of corrosion in reinforcement. The study revealed that an increase in the proportion of slag decreases the corrosion of reinforcement.

Wang and Trettin (2005) presented the influence of fineness and particle size distribution of granulated blast-furnace slag (GGBFS) on its hydraulic reactivity in cement systems. Wang and Miao (2012) reported the influence of high temperature curing at early ages on the hydration characteristics of a complex binder containing ground granulated blast furnace slag (GGBFS). Tamilarasan and Perumal (2012) studied the workability of concrete with GGBFS as a cement replacement material with and without the addition of super-plasticizer. Moreover, some of the studies (Bijen 1996, Li *et al.* 2009, Zhi Ge *et al.* 2009, Gardner and Susan 2015) studied the behaviour of concrete made from both- fly ash and ground granulated blast furnace slag combinedly.

Based on the afore-mentioned review of literature, an effort is made in this investigation to study the combined effect of fly ash and ground granulated blast furnace slag (GGBFS) as a cement replacing materials in conjunction with ordinary Portland cement for different water cement ratio on the compressive, split tensile and flexural strengths of the concrete through an experimental investigation. The chemical admixture was also added in the concrete mix to ensure the effect of workability.

3. Experimental programme

The particulars of the materials used in the present investigation along with the methodology of investigation are described in this section.

3.1 Materials

The materials used in the study include cement, sand, aggregates, water, admixtures and

Table 1 Properties of materials

Properties	Value
Cement	
Fineness (IS: 4031 Part II)	305 (Minimum225 cm^2/gm)
Consistency	28 %
Specific Gravity	3.00
Setting Time	
Initial Setting Time	130 Min (Minimum 30 Min)
Final Setting Time	221 Min (Maximum 600 Min)
Compressive strength	
• 3 Days' curing	29 MPa
• 7 Days' curing	36 MPa
• 28 Days' curing	54 MPa
Aggregates	
Specific Gravityof Fine aggregates	2.72
Specific Gravityof Coarse aggregate-20 mm	2.82
Specific Gravityof Coarse aggregate-10 mm	2.70

cement replacing materials such as fly ash and ground granulated blast furnace slag (GGBFS). The cement used in the said investigation comprised of Ordinary Portland Cement (ACC: 53 Grade). While the sand brought from Tapi River (Gujarat) was used in the study, the coarse aggregates (Metal I and II) procured from the local quarry at Turbhe in Navi Mumbai were used. The fresh fly ash (Pozzocrete 60) (Source: Nasik Thermal Power Station) made available by Dirk India Private Limited, Borivali Mumbai was brought into use for the purpose of this study. The GGBFS (Durocem BS 6699) was procured from Heidelberg Cement India Limited, Pen (India). The potable water was added for obtaining concrete mix.

The physical properties of the constituents of concrete obtained through various laboratory tests are summarized in Table 1.

The chemical admixture (plasticizer) Supercon® -100 was also used in the present study. This admixture was supplied by Krishna Conchem Products Pvt. Ltd., Mahape, Navi Mumbai. The particulars of the admixture were provided by the supplier. According to this, Supercon® -100 is a pure melamine based superplasticizer which when added to concrete/mortar/plaster modifies the properties of concrete such as workability, strength, permeability, cohesion etc. The plasticizer Supercon® -100 renders the mix very cohesive. It is capable of reducing the permeability by up to 94%. It enhances resistance against thermal stresses. It increases workability and reduces w/c ratio. Though its application is normally found in case of generalized reinforced cement concrete construction, it is highly recommended in the construction of water tanks, basements, foundations, floorings, bridge decks etc.

The technical specification of Supercon® -100 are given in Table 2. Supercon® -100 is added to concrete by weight cement mix after stirring in little water and then the solution is added after adding other ingredients in the mixer. Supercon® -100, when added in fresh concrete /mortar/plaster disperse cement uniformly in the mix. Due to deflocculating action on cement

Table 2 Particulars of the Supercon® -100

Base	Sulphonated Melamine Formaldehyde resin
Dosage	0.5% upto 2% as pre Workability requirements
Colour	Clear to Little Hazy
Water Reduction:	Between 15% to 20% (Conforms to IS 9103 – 1999 ASTM – C – 494 Type F)
pH	> 8.0
Stability	12 months in closes container
Packing	5 Kgs, 30 Kgs, 230 Kgs

(Source: Krishna Conchem Products Pvt. Ltd., Mahape, Navi Mumbai)

agglomerates the entrapped water is released and would be available for workability.

3.2 Methodology of investigation

The experimental programme involved the combination of Ordinary Portland Cement (OPC) and mineral admixtures such as fly ash (FA) and ground granulated blast furnace slag (GGBFS). For this combination the various parameters such as water cement ratio, percentage of cement, fly ash, GGBFS, fine and coarse aggregates; and chemical admixture (Supercon-100) were kept in varying proportions. On the backdrop of the literature, the percentage variation in cement replacing materials and cement was decided. The eight trial mixes were prepared. In each trial, 12 cubes, 3 beams and 3 cylinders were cast.

Cement, sand, coarse aggregate and cement replacing materials were thoroughly mixed in dry state by machine so as to obtain uniform color. The required percentages of admixture were added to the water calculated for the particular mix. Then, the required water as per the designated water cement ratio was added to the dry mix in order to obtain uniform mixture. The compaction factor test and slump test were carried out on fresh concrete and the respective values were recorded for all the trial mixes. The moulds with standard dimensions i.e., 150×150×150 mm were filled with concrete in 3 layers by poking with tamping rod and vibrated by the table vibrator. The vibrator was used for 30 second and it was maintained constant for all specimens. Along similar lines, the beams of size 100×100×500 mm and cylinders of size 100 mm diameter and 300 mm length were also cast.

The samples (cubes, beams and cylinders) were air dried for a period of 24 hours and then, they were weighed to find out their weight prior curing. Thereafter, they were immersed in water. The cubes were allowed for 7, 28, 40 and 90 days' curing while the beams and cylinders were allowed for 7, 28 and 40 days' curing. The samples were tested for their respective strengths.

4. Results and discussion

The effect of cement replacing materials such as fly ash and GGBFS when used in varying proportions in conjunction with OPC for different water cement ratio is studied on the mechanical

Table 3 Details of various trial mixes and compressive strengths (N/mm^2)

Trial No	w/c ratio	Cement (%)	Fly Ash (%)	GGBFS (%)	Strength (N/mm^2) for different curing period			
					7 Days	28 Days	40 Days	90 Days
1	0.47	55	22.5	22.5	20.14	32.00	36.00	39.00
2	0.45	60	20	20	22.81	38.66	37.19	42.96
3	0.43	65	17.5	17.5	30.37	41.48	45.48	49.77
4	0.41	70	15	15	33.18	40.00	42.37	48.44
5	0.39	75	12.5	12.5	33.00	36.44	39.25	44.74
6	0.37	80	10	10	40.59	54.81	54.37	55.70
7	0.35	85	7.5	7.5	46.81	57.63	58.07	58.22
8	0.33	90	5.0	5.0	45.33	55.25	57.33	63.70

properties of concrete made from the pozzolanic waste, in the context of the results obtained following different tests on fresh and hardened concrete and discussed in the subsequent sections.

4.1 Compressive strength

The particulars of different trial mixes with varying proportions of cement and cement replacing materials and varying water cement ratio are given in Table 3. The values of the compressive strengths for different curing periods are also indicated in Table 3. With increase in cement contents, the compressive strength of the concrete is found to increase for any curing period. Further, the compressive strength is found to increase with increase in curing period in respect of all the trial mixes.

For higher water cement ratio of 0.47, the percentage variation in the compressive strength is observed to be on higher side with respect to 7 days' strength. The percentage increase is found to be 58.88, 78.74, 93.64 for 28, 40 and 90 days' curing periods, respectively when compared with the strength obtained after 7 days' curing. For lower water cement such as 0.33 used in the present investigation, the corresponding variation is observed to be 21.88, 26.47 and 40.52, respectively.

For controlled mix with water cement ratio of 0.37, less variation in strength is observed. For 28 days' curing period, the percentage increase in strength is observed to be 35.03. For 40 and 90 days' curing period, the values are 33.94 and 37.22% in respect of 7 days' curing period.

The target compressive strengths of the design mix corresponding to 0.37 water cement ratio for 7 and 28 days' curing and the values of the observed compressive strengths of the controlled mix with water cement ratio of 0.37 are shown in Table 4.

The strength of the controlled mix is found to be 12.75% more as compared to that observed in case of design mix for 7 days' curing. However, this increase in strength is found to reduce for higher curing period of 28 days, i.e., 1.5%.

Similarly, the modulus of elasticity corresponding to the actual strength observed in case of the controlled mix with 0.37 water cement ratio and the strength of the design mix are also calculated as per the guideline given in IS: 456-2000. In case of the former, the modulus is found to be 37.01×10^3 N/mm^2 whereas in case of latter, 36.74×10^3 N/mm^2. The performance of the various mixes with respect to cement contents, water cement ratio, curing periods and that of cement replacing materials is discussed below.

Table 4 Compressive strengths of the design mix and the controlled mix (N/mm^2)

Water cement ratio	Mix design strength		Strength of the controlled mix	
	7 days	28 days	7 days	28 days
0.37	36	54	40.59	54.81
	Percentage variation		12.75	1.5

4.1.1 Effect of cement contents

The increase in compressive strength with cement contents is attributed to the increase in the availability of alkali (which is by-product of hydration of cement) for pozzolanic reaction. Further, the rate of gain in the strength is found to be high for higher cement contents.

In respect of 7 days' curing, the value of the strength is found to be 20.15 N/mm^2 for the first trial mix for cement content 11.61 kg and it goes on increasing to 39 N/mm^2. The increase in strength found to be 93% approximately. For 28 days' curing period, the difference goes on increasing with increase in cement contents. The compressive strength increases from 32 N/mm^2 for first trial mix to 55.25 N/mm^2 for the last trial mix. The difference between the strength in respect of first trial mix and last trial mix when cured for 7 days' is observed to be 125% for the increase in cement content from 11kg to 19kg. For the 28, 40 and 90 days' the corresponding difference between the strengths is observed to be 73%, 59% and 63% respectively. The value of compressive strength for 28, 40 and 90 days' curing period is observed to be on higher side than that of 7 days' strength.

4.1.2 Effect of the contents of cement replacing material

As evident from Table 3**,** the contents of fly ash and GGBFS were decreased from first trial mix (No. 1) to the last one, i.e., No. 8. However, its proportion was kept same, i.e., out of total amount of cement replacing materials for any trial, 50% would be the contents of each of these cement replacing materials.

It is observed that out of total cement content if 45% of cement is replaced by the fly ash and GGBFS for the first trial, the strength is found to increase for all the curing periods considered in the study. The strength corresponding to 7 days' curing is observed to be 20.14 N/mm^2 which is more than 59% of the strength obtained corresponding to 28 days' curing. Further, the strength obtained with respect to 40 days' curing is found to be 12.5% higher than that of the strength obtained for 28 days' curing. Similarly, the strength corresponding to 90 days' curing is found to be 8.33% more than that obtained for 40 days' curing. As the percentage of cement replacing materials goes on decreasing and percentage of cement in the mixes goes on increasing, the strength is observed to be on higher side in respect of all the trial mixes, considered in the present investigations, for all curing periods.

4.1.3 Effect of curing period

The compressive strengths in respect of various trial mixes for different curing periods are already mentioned in Table 3. Its graphical representation is shown in Fig. 1.

It is observed from Fig. 1 that the compressive strength is found to increase with increase in the cement content and the curing period for all the trial mixes. This is attributed to the increase in the availability of alkali (which is by-product of hydration of cement) for pozzolanic reaction. Further, the rate of gain is found to be high for higher curing periods.

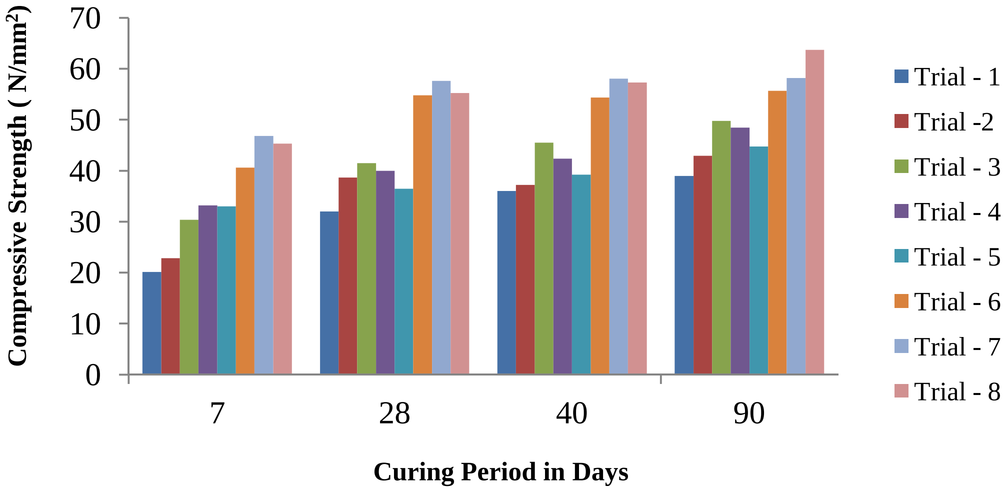

Fig. 1 Variation in compressive strength with curing period for different trial mixes

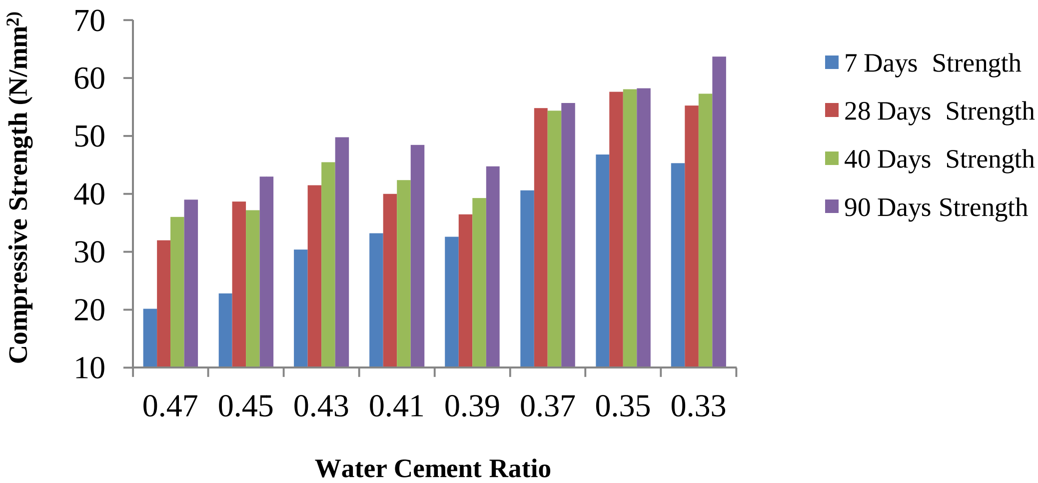

Fig. 2 Variation in compressive strength with water cement ratio

4.1.4 Effect of water cement ratio

Water cement ratio is varied from 0.33 to 0.47, the former one being used in the last trial mix whereas the last one, in the first trial mix. It is already mentioned in Table 3. The graphical representation shown in Fig. 2 illustrates the effect of water cement ratio on the compressive strength.

It is seen from Fig. 2 that with increase in water cement ratio, the compressive strength of concrete mix is found to decrease in respect of all the periods of curing considered in the present

Table 5 The values of the compressive strengths and compaction factor

Days	T- 1	T-2	T-3	T-4	T-5	T-6	T-7	T-8
7	20.15	22.82	30.37	33.19	33.00	40.59	46.81	45.33
28	32.00	38.67	41.48	40.00	36.44	54.81	57.63	55.26
40	36.00	37.19	45.48	42.37	39.26	54.37	58.07	57.33
90	39.00	42.96	49.78	48.44	44.74	55.70	58.22	63.70
Compaction Factor	0.98	0.98	0.97	0.93	0.895	0.88	0.895	0.87

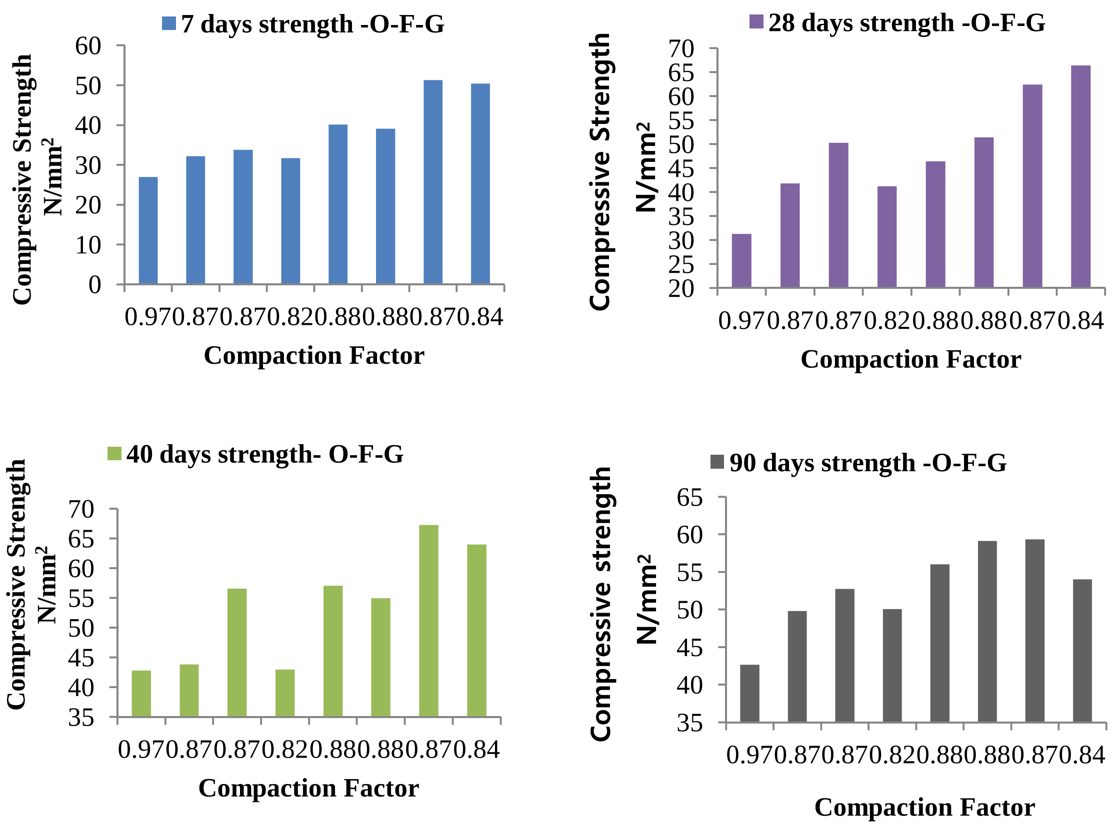

Fig. 3: Variation in compressive strength with compaction factor (7, 28, 40 and 90 days' curing period)

study. Further, the compressive strength of the concrete is obtained on higher side for the water cement ratio 0.33, as used in the last trial mix, in respect of all the curing periods.

4.1.5 Effect of compaction factor

The values of the compressive strengths in respect of different trial mixes and various curing periods considered in the present investigation vis-à-vis compaction factor is shown in Table 5.

Similarly, Fig. 3 shows the effect of compaction factor for different periods of curing on compressive strength of concrete. For higher values of the compaction factor, the compressive

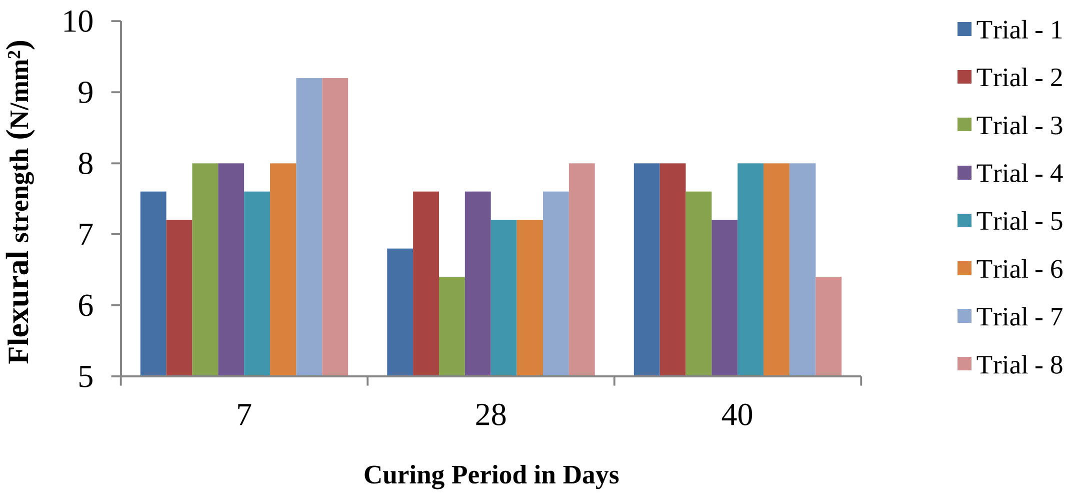

Fig. 4 Variation in flexural strength with curing period

strength is found to be less and with decrease in the compaction factor, the strength is found on the higher side. This holds good for all the curing period.

5. Flexural strength

The variation of the flexural strengths, as obtained from the modulus of rupture tests, for the various trial mixes in respect of all the curing period, is shown in Fig. 4.

From the values of the flexural strengths as mentioned in Table 5, the strength in respect of trial mixes 1, 2 and 5 is found on lesser side with respect to 7 days curing as compared to 40 days' curing. The strength with respect to 7 and 40 days' curing is found to be same in case of trial mix 6. In all other trial mixes, the strength with respect to 7 days' curing is found to be on higher side. Further, the flexural strength obtained with respect to 7 days' curing is found to decrease for the next curing period (28 days) and thereafter, it increases for the last curing period (40 days) considered in the present investigation, in respect of trial mixes 1 and 5. In respect of trial mix 2, the strength is found to increase with curing period. In trial mixes 3 and 7 where the strength is on higher side for lesser curing period (7 days), the strength is found to decrease at next curing period (28 days) and again increase for the next higher curing period (40 days). For trial mixes 4 and 8, the strength is found to decrease with curing period. In trial mix 6, where the strength corresponding to 7 days' and 28 days' curing is observed to be identical, the strength for 28 days curing period is less.

When the variation in flexural strength corresponding to 28 and 40 days' curing is compared with the strength obtained after 7 days' curing, it is found to be on the lesser side by 10.5 % for 28 days' curing period in case of higher water cement ratio (0.47). However, the strength is found to be on higher side by 5.26% for 40 days' curing period. However, for lower water cement ratio, i.e., 0.33, the corresponding variation is observed to be on lesser side by 13% and 30.4% .

For controlled mix with 0.37 water cement ratio, the strength after 28 days' curing period is observed to be decreased by 10% when compared with that obtained after 7 days' curing period. However, there is no effect on flexural strength corresponding to 40 days' curing since the strength for 7 days' curing and 40 days' curing is found to be same.

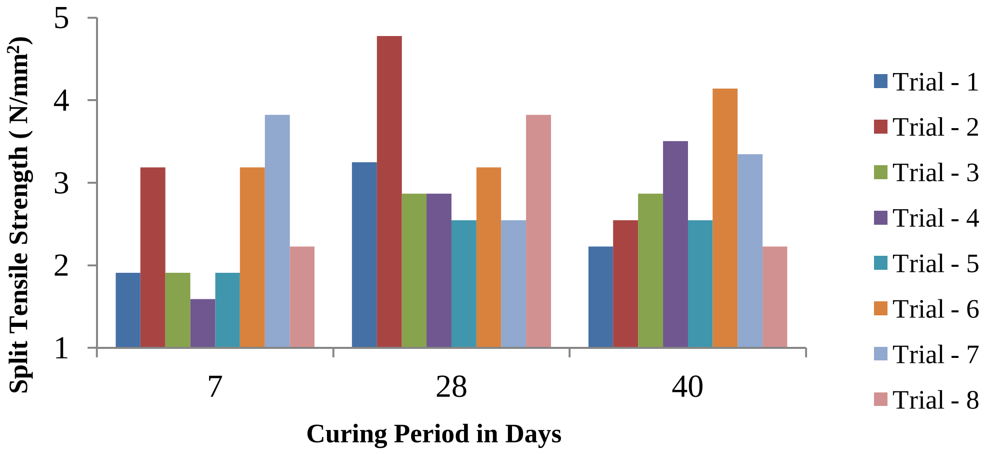

Fig. 5 Variation in split tensile strength with curing period

6. Split tensile strength

The variation of tensile strength with curing period, as obtained from the split tensile strength, for various trial mixes is shown in Fig. 5.

The strength in respect of trial mixes 1,2 and 8 is found on lesser side for 7 days' curing as compared to 28 and 40 days' curing. The 28 days' strength is found to be on higher side than that of 7 and 40 days' strength for trial mixes 1, 2 and 8.

Further, the tensile strength obtained with respect to 7 days' curing for trial mixes 3 and 5 is observed to be identical and is found to decrease compared to 28 and 40 days' curing periods. Also for the trial mixes 3 and 5, tensile strength value is observed to be same for 28 and 40 days' curing periods. In trial mixes 4 where the strength is observed to be on lower side for lesser curing period (7 days), the strength is found to increase at next curing period (28 days) and again increase for the next higher curing period (40 days).

In trial mixes 7 where the strength is on higher side for lesser curing period (7 days), the strength is found to decrease at next curing period (28 days) and again increase for the next higher curing period (40 days). In trial mix 6, where the strength corresponding to 7 days' and 28 days' curing is observed to be identical, the strength for 40 days' curing period is more.

The percentage variation in split tensile strengths with respect to 7 days' strength values is also studied. For higher water cement ratio (0.47), the increase in strength corresponding to 28 days' curing is found to be 70.15% and that corresponding to 40 days' curing is found to be 16.75% when compared with that obtained corresponding to 7 days' curing. More variation is observed for

28 days' curing period. However, the variation is observed to be less for higher curing period.

For less water cement ratio, the percentage variation is observed only for 28 days' curing period. The percentage increase in split tensile strength is found to be 71.30. For 40 days; curing period, no variation in strength is observed.

For controlled mix (water-cement ratio 0.37), the percentage variation is observed only for 40 days' curing period. The strength is found to be increased by 29.8% when compared with that observed corresponding to 7 days' curing.

7. Conclusions

The present experimental investigations were aimed at evaluating the suitability of the industrial waste containing pozzolanic materials such as fly ash and ground granulated blast furnace slag as the cement replacing materials in the concrete as a sustainable construction material. Some of the broad conclusions deduced from the present study are as follows.

- With increase in cement contents and decrease in the contents of fly ash and GGBFS, the compressive strength of the concrete is found to increase for any curing period.
- The compressive strength for all the mixes is found to increase with the increase in cement content. The compressive strength of concrete mix is found to decrease with increase in water-cement ratio in respect of all the periods of curing and vice versa.
- For higher water cement ratio, the increase in compressive strengths for higher curing period is on higher side when compared with the strength corresponding to 7 days' curing while the increase is less in case of the mixes with lower water cement ratio.
- The compressive strength of the controlled mix (water-cement ratio 0.37) is 12.75% and 1.5% more as compared to the strength observed in the design mix.
- With increase in compaction factor, the compressive strength of the concrete decreases. The gain in compressive strength up to 28 days' curing is considerable. However, the rate of gain in strength beyond 28 days' curing period is not that significant.
- The variation in the flexural strength of the concrete for 7, 28 and 40 days' curing is not considerable and so in case of split tensile strength.
- For higher water cement ratio considered in the study, the flexural strength is found to increase for 28 days' curing when compared with the strength corresponding to 7 days' curing. However, there is decrease in strength for higher curing period of 40 days. For the controlled mix with water cement ratio of 0.37, there is decrease in strength for 40 days' curing while no effect on strength is seen for higher curing period of 40 days.
- The tensile strength of the concrete is on the lowest side. For higher water cement-ratio, the tensile strength is found to increase for higher curing period considered in the present study when compared with the strength corresponding to 7 days' curing while in case of lower cement ratio, the increase in strength is observed only for 28 days' curing. In case of controlled mix, the increase in strength is observed only for 40 days' curing.
- The flexural strength is 2.5 to 3 times more than the tensile strength. However, the compressive strength is considerably higher than the tensile and flexural strength.
- The curing period hardly improves the flexural and tensile strength of the concrete.

In view of the afore-mentioned findings emerged from the present investigation, it can be concluded that the pozzolanic waste materials such as fly ash and GGBFS when used as a cement replacing materials in conjunction with OPC can render the sustainable concrete.

References

Aggarwal, V. and Gupta, S.M. (2010), "Concrete durability through high volume fly ash concrete (HVFC): A literature review", *Int. J. Eng. Sci. Tech.*, **2**(9), 4473-4477.

Aggarwal, V. and Gupta, S.M. (2012), "High volume fly ash concrete: a green concrete", *J. Envir. Res. Develop.*, **6**(3A).

Alam, J. and Akhtar, M.N. (2011), "Fly ash utilization in different sectors in Indian scenario", *Int. J. Emerg. Trend. Eng. Develop.*, **1**(1), 1-14.

Babu, G. and Kumar, K. (2000), "Efficiency of GGBFS in concrete", *Cement Concrete Res.*, **30**(7), 1031-1136.

Bijen, J. (1996), "Benefits of slag and fly ash", *Constr. Build. Mater.*, **10**(5), 309-314.

Daube, J. and Bakker, R. (1986), "Portland blast furnace slag cement: a review", *American Society for Testing and Materials (Blended cement, ASTM STP- 897)*, Ed. G. Frohnsdorff, Philadelphia, 5-14.

Dhadse, S., Pramila, Kumari and Bhagia, L.J. (2008), "Fly ash characterization, utilization and government initiatives in India", *J. Sci. Ind. Res.*, **67,** 11-18.

Dubovoy, V.S., Gebler, S.H. and Klieger, P. (1986), "Effects of Ground Granulated Blast Furnace slag on some properties of pastes, mortars and concretes", *American Society for Testing and Materials(Blended cement, ASTM STP- 897)*, Ed. G. Frohnsdorff, Philadelphia, 29-48.

Olorunsogo, F.T. and Wainwright, P.J. (1998), "Effect of GGBFS particle-size distribution on mortar compressive strength" , *J. Mater. Civ. Eng.*, **10**, 180-187.

Frigione, G. (1986), "Manufacture and characteristics of Portland blast furnace slag cements", *American Society for Testing and Materials(Blended cement, ASTM STP- 897)*, Ed. G. Frohnsdorff, Philadelphia, 15-28.

Gardner, L.J. and Susan, A. (2015), "Characterization of magnesium potassium phosphate cements blended with fly ash and ground granulated blast furnace slag", *Cement Concrete Res.*, **74**,78-87.

Hooton, R.D. (2000), "Canadian use of ground granulated blast furnace slag (GGBFS) as a supplementary cementing material for enhanced performance of concrete", *Can. J. Civil Eng.*, **27**, 754-760.

Kohubu, M. (1969), "Fly ash and fly ash cement", *Proceedings of the Fifth International Symposium on the Chemistry of Cement, Cement Association of Japan, Tokyo*, **IV**, 75-105.

Li, D.J., Shen, Y. and Chen, L. (2000), "Study of properties on fly ash-slag complex cement", *Cement Concrete Res.*, **30** (3), 1381-1387.

Malhotra, V.M. (1999), "Making concrete 'Greener' with fly ash", *Information Portal International Concrete Research and Information Portal Concrete International*, **21**(5), 61-66.

Meusel, J.W. and Rose, J.H. (1983), "Production of granulated blast furnace slag at sparrows point, and the workability and strength potential of concrete incorporating the slag", *American Concrete Institute (SP-79)*, 867-90.

Obla, K.H. and Russell, L.H. (2003), "Properties of concrete containing ultra-fine fly ash", *ACIMater. J.*, **100**(5), 426-433.

Oluokun, F.A. (1994), "Fly ash concrete mix design and the water-cement ratio law", *ACI Mater. J.*, **91**(4), 362-371.

Osborne, G.J. (1999), "Durability of Portland blast furnace slag cement concrete", *Cement Concrete Comp.*, **21**(1), 11-21.

Pal, S.C., Mukherjee, A. and Pathak, S.R. (2002), "Corrosion behavior of reinforcement in slag concrete", *ACI Mater. J.*, **99**(6), 521-527.

Silva, P. and Brito, J. (2013), "Electrical resistivity and capillarity of self-compacting concrete with

incorporation of fly ash and limestone filler" , *Adv. Concrete Constr.*, **1**(1), 65-84.
Sunil, B.M., Manjunatha, L.S., Ravi, L. and Yaragal, S.C. (2015), "Potential use of mine tailings and fly ash in concrete", *Adv. Concrete Constr.*, **3**(1), 55-69.
Tamilarasan, V.S. and Perumal, P. (2012), "Workability studies on concrete with GGBFS as a replacement material for cement with and without super-plasticizers", *Int. J. Adv. Res. Eng. Tech. (IJARET)*, **3**(2), 11-21.
Wang, P.Z. and Trettin, R. (2005), "Effect of fineness and particle size distribution of granulated blast-furnace slag on the hydraulic reactivity in cement systems", *Adv. Cement Res*., **17**(4), 161-167.
Wang, Q. and Miao, M. (2012), "The influence of high-temperature curing on the hydration characteristics of a cement-GGBS binder", *Adv. Cement Res*., **24**(1), 33-40.
Wimpenny, D.E., Ellis, C. and Reeves, C.M. (1989), "Development of strength and elastic properties in slag cement concretes under low temperature curing conditions", *Proc. 3rd International Conference on fly ash, silica fume, slag and natural Pozzolanas in concrete,Trondheim, Norway*, **2.**
Yang, W. and Li, Q. (2012), "On effects of fly ash as a partial replacement of cement on concrete strength", *Appl. Mech. Mater.*, 204-208.
Ge, Z. and Wang, K. (2009), "Modified heat of hydration and strength models for concrete containing fly ash and slag", *Comput. Concrete*, **6**(1), 19-40.

CC